

Claims

What is claimed is:

- [c1] A method for deghosting and water surface multiple reflection attenuation in dual sensor marine seismic data, comprising:
 - decomposing the data acquired at each of a plurality of source positions into upgoing and downgoing wavefield components using a measured parameter related to pressure and measured parameter related to vertical particle motion, the decomposing comprising transforming the data into the spatial frequency domain and separating the upgoing and downgoing wavefield components in the transformed data; and
 - determining a substantially multiple-free wavefield from the decomposed wavefield components.
- [c2] The method of claim 1 wherein the data are acquired at a plurality of spaced apart locations at a selected depth below the water surface using a dual sensor streamer.
- [c3] The method of claim 2 wherein the selected depth is below a depth of a seismic energy source.
- [c4] The method of claim 1 wherein the data are acquired using an ocean bottom cable.
- [c5] The method of claim 1 wherein the parameter related to pressure comprises change in pressure with respect to time.
- [c6] The method of claim 1 wherein the parameter related to vertical particle motion comprises particle velocity.
- [c7] The method of claim 1 wherein the parameter related to vertical particle motion comprises particle acceleration.

- [c8] The method of claim 1 wherein the determining the substantially multiple free wavefield comprises solving a system of equations for measured total wavefield and multiple free wavefield at the plurality of source positions.
- [c9] The method of claim 1 further comprising determining a source wavelet from the decomposed wavefield components.
- [c10] A method for deghosting marine seismic data, the data comprising measurements of a vertical component of a parameter related to particle motion and a parameter related to pressure, the measurements related to pressure and particle motion substantially collocated and made at a plurality of spaced apart positions, the method comprising:
 - transforming the data into the spatial frequency domain;
 - separating an upgoing wavefield component of the transformed data in the spatial frequency domain; andinverse transforming the upgoing component into the time-space domain.
- [c11] The method of claim 10 wherein the parameter related to pressure comprises change in pressure with respect to time.
- [c12] The method of claim 10 wherein the parameter related to vertical particle motion comprises particle velocity.
- [c13] The method of claim 10 wherein the parameter related to vertical particle motion comprises particle acceleration.
- [c14] The method of claim 10 wherein the data are acquired at a selected depth below the surface of the body of water using a dual sensor streamer.
- [c15] The method of claim 10 wherein the data are acquired using an ocean bottom cable.
- [c16] A method for seismic exploration, comprising:
 - actuating a seismic energy source in a body of water at a plurality of positions;

measuring a parameter related to pressure at a plurality of locations at a selected depth below the surface of the body of water;

measuring a parameter related to a vertical component of particle motion at substantially the same locations as measuring the parameter related to pressure;

decomposing the measurements of the pressure related parameter and particle motion parameter acquired at each of the plurality of source positions into upgoing and downgoing wavefield components; and

determining a substantially multiple-free wavefield from the decomposed wavefield components.

- [c17] The method of claim 16 wherein the selected depth is below a depth at which the seismic energy source is actuated.
- [c18] The method of claim 16 wherein the parameter related to pressure comprises change in pressure with respect to time.
- [c19] The method of claim 16 wherein the parameter related to vertical particle motion comprises particle velocity.
- [c20] The method of claim 16 wherein the parameter related to vertical particle motion comprises particle acceleration.
- [c21] The method of claim 16 wherein the determining the multiple free wavefield comprises solving a system of equations for measured total wavefield and multiple free wavefield at the plurality of source positions.
- [c22] The method of claim 16 wherein the decomposing comprises:
 - transforming the data into the spatial frequency domain;
 - separating an upgoing wavefield component of the transformed data in the spatial frequency domain and
 - inverse transforming the upgoing component into the time-space domain.

- [c23] The method of claim 16 further comprising determining a source wavelet from the decomposed wavefield components.
- [c24] The method of claim 16 wherein the data are acquired using a dual sensor streamer.
- [c25] The method of claim 16 wherein the data are acquired using an ocean bottom cable.
- [c26] A computer program stored in a computer readable medium, the program including logic operable to cause a programmable computer to perform steps comprising:
 - decomposing seismic signals acquired at each of a plurality of seismic energy source positions into upgoing and downgoing wavefield components using a measured parameter related to pressure and measured parameter related to vertical particle motion, the decomposing comprising transforming the data into the spatial frequency domain and separating the upgoing and downgoing wavefield components from the transformed data; and
 - determining a substantially multiple-free wavefield from the decomposed wavefield components.
- [c27] The program of claim 26 wherein the seismic signals are acquired at a plurality of spaced apart locations at a selected depth below a water surface.
- [c28] The program of claim 27 wherein the selected depth is below a depth at which a seismic energy source is disposed.
- [c29] The program of claim 26 wherein the parameter related to pressure comprises change in pressure with respect to time.
- [c30] The program of claim 26 wherein the parameter related to vertical particle motion comprises particle velocity.
- [c31] The program of claim 26 wherein the parameter related to vertical particle motion comprises particle acceleration.

- [c32] The program of claim 26 wherein the logic comprises instructions operable to cause the computer to perform solving a system of equations for measured total wavefield and multiple free wavefield at the plurality of source positions.
- [c33] A method for seismic exploration, comprising:
 - towing at least one seismic energy source in a body of water;
 - towing at least one seismic streamer at a selected depth in the body of water, the streamer having a plurality of sensor sets thereon, each of the plurality of sensor sets having therein a first sensor adapted to measure a parameter related to pressure of the water and a second sensor adapted to measure a parameter related to a vertical component of particle motion at substantially the same locations as first sensor;
 - actuating the seismic energy source at a plurality of positions in the water;
 - measuring signals generated by each of the first and second sensors in the sensor sets in response to each of the actuations of the source;
 - decomposing the measurements of the pressure related parameter and particle motion parameter acquired at each of the plurality of source positions into upgoing and downgoing wavefield components; and
 - determining a substantially multiple-free wavefield from the decomposed wavefield components.
- [c34] The method of claim 33 wherein the selected depth is below a depth at which the seismic energy source is actuated.
- [c35] The method of claim 33 wherein the parameter related to pressure comprises change in pressure with respect to time.
- [c36] The method of claim 33 wherein the parameter related to vertical particle motion comprises particle velocity.
- [c37] The method of claim 33 wherein the parameter related to vertical particle motion comprises particle acceleration.

- [c38] The method of claim 33 wherein the determining the multiple free wavefield comprises solving a system of equations for measured total wavefield and multiple free wavefield at the plurality of source positions.
- [c39] The method of claim 33 wherein the decomposing comprises transforming the measurements related to pressure and particle motion into the spatial frequency domain, and separating the upgoing and downgoing components in the transformed measurements.
- [c40] The method of claim 33 further comprising:
 - deploying at least one ocean bottom cable having a plurality of substantially collocated sensor pairs at spaced apart positions thereon, the sensor pairs including a sensor responsive to a parameter related to pressure and a sensor responsive to particle motion;
 - measuring signals generated by each of sensors in the sensor pairs in response to each of the actuations of the source;
 - decomposing the measurements of the pressure related parameter and particle motion parameter acquired at each of the plurality of source positions into upgoing and downgoing wavefield components; and
 - determining a substantially multiple-free wavefield from the decomposed wavefield components.